A STUDY ON THE EFFECT OF CHEMICAL TREATMENT ON THE MECHANICAL BEHAVIOUR OF BAMBOO-GLASS FIBER REINFORCED EPOXY BASED HYBRID COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
in
Mechanical Engineering

By

Suyash Sahay

Roll No. 108ME067

DEPARTMENT OF MECHANICAL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA 769008

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CERTIFICATE

This is to certify that the thesis entitled ***"A Study on the Effect of Chemical Treatment on the Mechanical Behavior of Bamboo-Glass Fiber Reinforced Epoxy Based Hybrid Composites"*** submitted by **Suyash Sahay (**Roll Number: **108ME067)** in partial fulfillment of the requirements for the award of **Bachelor of Technology** in the Department of Mechanical Engineering, National Institute of Technology, Rourkela, is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted elsewhere for the award of any degree.

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A C K N O W L E D G E M E N T

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ABSTRACT

Fiber reinforced polymer composites have a wide variety of applications as a class of structural materials because of their advantages such as ease of fabrication, relatively low cost of production & superior strength as compared to neat polymer resins. The fiber which serves as a reinforcement in polymers may be either synthetic or natural. Although synthetic fibers such as glass, carbon etc. possess high specific strength, their field of applications are limited because of their higher costs of production. Recently, there is an increasing interest in hybrid composites that are made by reinforcement of two or more different types of fibers in a single matrix, because these materials attain a range of properties that cannot be obtained with a particular kind of reinforcement. Further, material costs can be reduced by careful selection of reinforcing fibers. Currently, the chemical treatments of the fibers are carried out as they further enhance the properties of the composites. In this connection, an investigation has been carried out to make potential utilization of bamboo fiber as reinforcement with glass fiber which is very cheap and is easily available in India. The objective of the present research work is to study the effect of chemical treatments on the mechanical properties of glass/bamboo fiber reinforced epoxy based hybrid composites.

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CHAPTER 1

INTRODUCTION

1.1 Introduction and background

Composites are either naturally occurring or engineered materials that are made from two or more constituents. In other words, composites are materials that consist of strong load carrying reinforcing material imbedded in a weaker matrix material. Basically composites have two constituents. The principal constituent of composites having a continuous phase and that forms the major part of the composite is called matrix. Matrix is usually less hard and is more ductile. Matrix can be either organic or inorganic. The secondary constituent has a discontinuous phase and is embedded in the matrix. This is known as reinforcement. The constituents of composites retain their individual physical and chemical properties, however when combined, they produce a combination of properties that individual constituents would be incapable of producing alone [48]. In the past decade, composite materials have been used as an alternative in several light weight and high strength uses because of their high strength-to-weight ratio and high tensile strength. With the continuous growth and development in technology, the need for different materials with highly specific properties is increasing day by day and these demands cannot be achieved by use of existing metal alloys, ceramics and polymers. This is where composites come into picture as various metals, ceramic and polymers can be mixed together to get the specifically desired properties. According to the type of matrix material, composites can be grouped [49] into the following categories:-

a) Polymer Matrix Composites (PMC)

b) Metal Matrix Composites (MMC)

c) Ceramic Matrix Composites (CMC)

Among various types of composites, the most commonly used composites are polymer matrix composites (PMCs) because of their many advantages such as low cost, high strength and simple manufacturing principles. In PMCs, there are two main types of polymers that are used as matrix. They are thermoplastic and thermosetting polymers. Thermoplastic polymers are those which can be repeatedly softened and reformed by heating. A few examples of thermoplastic polymers are PVC, LDPE and HDPE. Thermosetting polymers are hard and stiff cross-linked materials which do not soften or become moldable when heated. Among different types of thermosetting polymers, epoxy is the most commonly used polymer because of its many advantages such as better adhesion to other materials, good electrical insulation, good mechanical properties, and its good resistance to chemical and environmental factors.

The other constituent of composites is ‘reinforcements’ which is as important as the matrix as it serves to improves the overall mechanical properties of the matrix and strengthen the composites. Now-a-days, the interest in natural fibers as reinforcement in polymer composites is increasing rapidly. The idea of using natural fibers as reinforcing material is not a new one as grass and straw have been used by man since the beginning of civilization to reinforce the bricks that were used to make mud walls. The advantages of natural fibres over traditional reinforcing materials are their acceptable specific strength properties, low cost, low density, good thermal properties, enhanced energy recovery and biodegradability [1]. Besides they are abundantly available, environmentally friendly and biodegradable. These advantages have made natural fibers a potential replacement for synthetic fibers such as glass fibers in composite materials.

Generally, natural fibers are considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix. These cellulose fibrils are aligned along the length of the fiber, irrespective of its origin. The composition of a few natural fibers is as shown in Table 1.1.

Table 1.1 Chemical compositions of natural fibers [2]

Fiber	Cellulose (Wt %)	Hemicelluloses (Wt %)	Lignin (Wt %)	Pectin (Wt %)	Moisture Content (Wt %)	Waxes
Cotton	85-90	5.7	-	0-1	7.85-8.5	0.6
Bamboo	60.8	0.5	32	-	-	-
Flax	71	18.6-20.6	2.2	2.3	8-12	1.7
Hemp	70-74	17.9-22.4	3.7-5.7	0.9	6.2-12	0.8
Jute	61.1-71.5	13.6-20.4	12-13	0.2	12.5-13.7	0.5
Kenaf	45-47	21.5	8-13	3-5		
Ramie	68.6-76.2	13.1-16.7	0.6-0.7	1.9	7.5-17	0.3
Banana	63-64	10	5		10-12	
Sisal	66-78	10-14	10-14	10	10-22	2
Coir	32-43	0.15-0.25	40-45	3-4	8	

Based on origin, natural fibers can be classified into three categories that are plant fibers, animal fibers and mineral fibers. The detailed classification of the fibers is as shown in Figure 1.1.

The mechanical properties of some natural fibers compared with most commonly used E-glass fiber is shown in Table 1.2. It is evident from the table that even though the modulus of natural fibers is similar to glass fibers, the tensile strength of glass fibers is much higher than the natural fibers. However, the specific modulus (modulus/ specific gravity) of both glass as well as natural fibers are comparable and in some cases, the value for natural fibers is even better than glass fibers. These higher specific properties are one of the main advantages of using natural fiber as reinforcement in polymer composites for applications where one of the aims is reduction of weight.

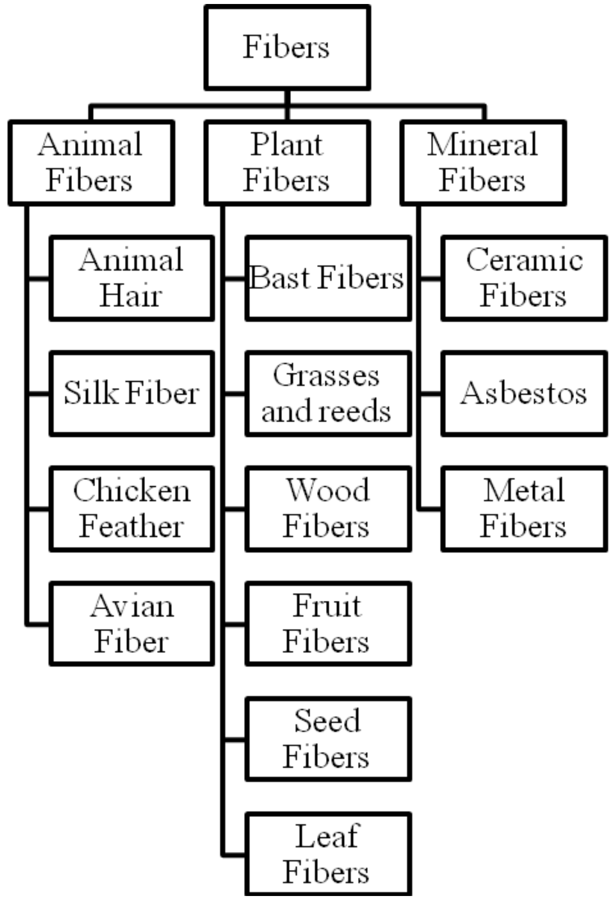

Figure 1.1 Classifications of Natural Fibers

1.2 Hybrid Composites

When more than one type of fibers are reinforced into a common matrix, the resulting composite is called hybrid composite. Hybrid composites provide greater freedom when it comes to designing composites for specific properties as compared to single fiber reinforced composites. Recently, natural fibers such as bamboo, jute etc.have been mixed with synthetic fibers such as glass to form hybrid composites with desired properties at low cost. The behavior of hybrid composites is a weighed sum of individual components in which there is a more favorable balance between the inherent advantages and disadvantages [50]. By using hybrid composites, the advantages of one type of fiber could compliment what is lacking in the other fiber. The properties of hybrids are decided by many factors such as fiber content, fiber length, orientation, extent of intermingling of fibers, fiber to matrix bonding etc.

Table 1.2 Properties of natural fibers [3]

Fiber	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12	3-10	1.5
Alfa	350	22	5.8	0.89
Bagasse	290	17	-	1.25
Bamboo	140-230	11-17	-	0.6-1.1
Banana	500	12	5.9	1.35
Coir	175	4-6	30	1.2
Cotton	287-597	5.5-12.6	7-8	1.5-1.6
Curaua	500-1,150	11.8	3.7-4.3	1.4
Date palm	97-196	2.5-5.4	2-4.5	1-1.2
Flax	345-1,035	27.6	2.7-3.2	1.5
Hemp	690	70	1.6	1.48
Henequen	500 ± 70	13.2 ± 3.1	4.8 ± 1.1	1.2
Jute	393-773	26.5	1.5-1.8	1.3
Kenaf	930	53	1.6	-
Oil palm	248	3.2	25	0.7-1.55
Pineapple	400-627	1.44	14.5	0.8-1.6
Ramie	560	24.5	2.5	1.5
Sisal	511-635	9.4-22	2.0-2.5	1.5
E-Glass	3400	72	-	2.5

Even though natural fibers have many advantages, their use is restricted because of several limitations. They are incompatible with some polymeric matrices, have high absorption and have poor wettability [1]. These are the problems faced even when the natural fibers are used in hybrid composites. In order to overcome these problems, chemical treatments are done. To this end, the present research work is undertaken to study the effects of chemical treatments on the mechanical properties and performance of bamboo-glass fiber reinforced epoxy based hybrid composite.

1.3 Thesis Outline

The remainder of this thesis is organized as follows:

Chapter 2: Previous work relevant to the present research is described in this chapter.

Chapter 3: This chapter describes the details of materials required, fabrication techniques and characterization of the composites under investigation.

Chapter 4: The mechanical behavior of bamboo/glass fiber reinforced epoxy based hybrid composites and the effect of chemical treatment on the performance are presented and discussed in this chapter.

Chapter 5: Conclusions and recommendations for future work are presented in this chapter.

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CHAPTER 2

LITERATURE SURVEY

The idea of this chapter is to provide the background information on the current research trends on the hybrid composites with special attention on the bamboo fiber based polymer composites and the effect of surface treatment on the mechanical behavior of natural fiber based hybrid composite.

2.1. Literature review

A number of investigations have already been carried out on several types of natural fibers such as hemp, flax, bamboo, jute and kenaf to study the effect of these fibers on the mechanical characteristics of composite materials [4-7]. In dynamic mechanical analysis, Laly et al. [8] have reported on banana fiber reinforced composites and obtained that the optimum percentages of banana fiber is 40wt.%. Effect of fiber content on tensile and flexural properties of pineapple fiber reinforced poly (hydroxybutyrate-co-valerate) resin composites has been studied by Luo and Netravali [9]. The fracture energies for fibers such as sisal, banana, pineapple and coconut fiber reinforced polyester composites using Charpy impact tests has been studied by Pavithran et al. [10]. They reported that, except for the coconut fiber, the fiber toughness increases due to increase in fracture energy of the composites. The mechanical behviour of jute and kenaf fiber reinforced polypropylene composites has been studied by Schneider and Karmaker [11]. Pothan et al. [12] reported that kraft pulped banana fiber composite has good flexural strength. Luo and Netravali [13] studied the mechanical properties like tensile and flexural strength of the green composites with different pineapple fibre percentage and compared with the virgin resin.

Belmeres et al. [14] reported that sisal, henequen, and palm fibre have similar physical, chemical, and tensile properties. A systematic study on the properties of henequen fiber has been made by Cazaurang et al. [15] and reported that fibers have mechanical properties suitable for reinforcement in thermoplastic resins. Various aspects of banana fiber reinforced polymer composites have been studied by various investigators [16-20]. Cazaurang et al. [21] have done a detailed study on the properties of henequen fibre and concluded that these fibres have mechanical properties suitable for reinforcing thermoplastic resins. The mechanical properties of jute faber reinforced polyester composites were evaluated by Gowda et al. [22]. It is reported from their study that they have better strengths as comparison to wood based composites. The use of cotton fibre reinforced epoxy composites along with glass fibre reinforced polymers was done by Khalid et al. [23]. The effect of various loading rate on mechanical properties of jute/glass reinforced epoxy based hybrid composites has been studied by Srivastav et al. [24].

Mohanty et. al. [25] explained the influence of different surface modifications of jute fiber on the performance of the biocomposites. More than 40% improvement in the tensile strength occurred as a result of reinforcement with alkali treated jute fiber. Jute fiber content also affected the bio-composite efficiency and about 30wt.% of jute fiber showed optimum properties of the biocomposites. Ismail et al. [26] studied the effect of bonding strength on mechanical properties of bamboo fiber reinforced natural rubber composites. Similarly, Rajulu et al. [27] studied the effect of fiber length on tensile properties of short bamboo fiber reinforced epoxy composites. However, Chen [28] studied the structure, morphology and properties of bamboo fiber reinforced composites in details. Sreekala et al. [29] reported on the mechanical performance of treated oil palm fiber-reinforced composites and studied the tensile stress-stain behavior of composites for 40wt.% fiber loading. Jiang et al [30] reported on the mechanical behaviour of poly(3-hydroxybutyrate-co-3-hydroxyvalerate)/bamboo pulp fiber composites. The tensile strength and modulus of bamboo fiber reinforced polypropylene based composites has been explained by Okubo et al. [31]. The mechanical properties of bamboo fiber reinforced polypropylene composites was studied and compared with commercial wood pulp by Chen et al. [32].

Several researchers have worked on chemical treatment of natural fibers and their effects. John et al. [33] have given a detailed study on the structure of natural fiber, their chemical composition and their mechanical properties. The mechanism of chemical modification has been explained along with several chemical treatments that have been performed on different natural fibers. Gomes et al. [34] have discussed the effect of alkali treatment of curauna fiber green composites for tensile properties. Joseph et al. [35] researched on the effect of chemical treatment on the tensile properties of short sisal fiber-reinforced polyethylene composites and have reported improvements in mechanical properties. Demir et al. [36] have found out that mechanical properties of luffa fiber reinforced polypropylene composites improved when treated with three different coupling agents (MAPP, MS and AS) and have attributed it to the better adhesion between fiber and matrix due to treatment of fibers. Weyenberg et al. [37] found out that treatment with alkali, dilute epoxy, acetone and silane improved the flexural strength, tensile strength and modulus as well as the transverse strength and modulus of flax fiber based composites to different extents. Paul et al. [38] showed that chemical treatments (alkali, benzoyl chloride, KMnO4and silane treatment) of banana fiber based polypropylene composites improved the thermo-physical properties (thermal conductivity and diffusivity) in each case. Kushwaha et al. [39-41] have found the optimum alkali percentage for best results and have discussed the effects of chemical treatments on mechanical properties bamboo fiber composites. Hongwei Ma et al. [42] have found out the effect of silane coupling under different types of radiation on the structural properties of bamboo fiber reinforced poly(lactic acid) bio composites.

2.2 The Knowledge gap

It can be seen from the above survey that although an exhaustive amount of research has been done on the effect of chemical treatment on mechanical properties of natural fiber reinforced composites, the research done on effects of chemical treatments on mechanical properties of hybrid composites is very less.

2.3 Objectives of the present research work

Following are the objectives that have been outlined keeping in mind the knowledge gap:

1. Fabrication of a new class of epoxy based hybrid composite reinforced with shortbamboo and glass fibers.
2. Evaluation of mechanical properties such as tensile strength, flexural strength and micro-hardness.
3. To study the influence of chemical treatments (alkali treatment and permanganate treatment) on mechanical behavior of bamboo-glass fiber reinforced epoxy based hybrid composites.

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CHAPTER 3

MATERIALS AND METHODS

This chapter details the materials and methods used for making the composites as well as the chemical treatments and the machines and methods used to characterize the composites.

3.1 Preparation of composites

The raw materials needed for manufacturing the composites are:

1. Epoxy resin
2. E-Glass Fiber
3. Short Bamboo Fiber
4. Hardener

Three sets of samples are to be prepared. One set without chemically treated fibers, second set with alkali treated fibers and third set with permanganate treated fibers. The procedure for chemically treating the fibers is as described below:

3.1.1 Alkali Treatment

Bamboo fibers were cleaned and dipped in 5% NaOH solution for 30 minutes at room temperature. After this, the bamboo fibers were filtered and thoroughly washed with distilled water and subsequently neutralized with 2% HCl solution. During the entire neutralizing time litmus paper test was carried out at proper intervals to check the neutrality. Finally the NaOH treated fibers were dried in an oven at $80^{o}C$ for 3 hours.

3.1.2 Permanganate Treatment

Bamboo fibers were initially dipped in 5% NaOH solution for 30 minutes at room temperature. Then they were filtered and washed properly with distilled water to remove sodium hydroxide. Following this, these fibers were soaked in 1%

Potassium permanganate in acetone solution for 20 minutes. Finally they were filtered and dried at $80^{o}C$ for 3 hours.

3.2. Sample Preparation

The short bamboo fiber which is taken as reinforcement in this study is collected from local sources. The epoxy resin and the hardener (HY951) are supplied by Ciba Geigy India Ltd. Wooden moulds having dimensions of 180 x 180 × 40 mm3 were first manufactured for composite fabrication. The chemically treated short bamboo fiber and E- Glass fibers are mixed with epoxy resin by simple mechanical stirring and the mixture was poured into various moulds, keeping in view the requirements of various testing conditions and characterization standards. The composite samples of three different compositions (SBGF-1 to SBGF-3) are prepared. The composite samples SBGF-1 to SBGF-3 are prepared having three different percentages of Bamboo fibers (5 wt %, 10 wt % and 15 wt %) and glass fibers(15 wt%, 10 wt%, 5wt %) respectively. This is done while keeping the epoxy content at a fixed percentage (i.e. 80 wt %), while keeping the length of the bamboo and glass fibers constant at 10 mm. The detailed composition and designation of composites are shown in Table 3.1. A releasing agent is used on the mould release sheets to facilitate easy removal of the composite from the mould after curing. The entrapped air bubbles (if any) are removed carefully with a sliding roller and the mould is closed for curing at a temperature of 30°C for 24 h at a constant load of 50 kg. After curing, the specimens of suitable dimension are cut using a diamond cutter for mechanical tests as per the ASTM standards. The composition and designation of the composites prepared for this study are listed in the following table. The samples have been prepared by varying fiber loading for the two fibers. Figures 3.1 and 3.2 show the KMnO4 and alkali treated bamboo/glass fiber reinforced epoxy composites.

Table 3.1. Designation of Composites

Composites	Compositions
SBGF-1	Epoxy (80 wt%)+Bamboo fiber (5 wt%, 10 mm)+Glass fiber (15 wt%)
SBGF-2	Epoxy (80 wt%)+Bamboo fiber (10 wt%, 10 mm)+Glass fiber (10 wt%)
SBGF-3	Epoxy (80 wt%)+Bamboo fiber (15 wt%, 10 mm)+Glass fiber (5 wt%)

Figure 3.1. Permanganate treated Bamboo- glass fiber reinforced hybrid composite

Figure 3.2. Alkali treated Bamboo-glass fiber reinforced hybrid composite

3.3 Mechanical testing of composites

The tension test was performed on all the three samples as per ASTM D3039-76 test standards. The tension test is generally performed on flat specimens. A uni-axial load is applied through the ends. The ASTM standard test recommends that the length of the test section should be 100 mm specimens with fibers parallel to the loading direction to be 11.5 mm wide.

To find out the flexural strength of the composites, a three point bend test is performed using TINIUS OLSEN HS10K. The cross head speed was taken as 10 mm/min and a span of 10 mm was maintained. The strength of a material in bending is expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure.

Leitz micro-hardness tester is used for micro-hardness measurement on composite samples. A diamond indenter in the form of a right pyramid of a square base of an angle 136° between opposite faces is forced under a load F into the sample. After removal of the load, the two diagonals of the indentation (X and Y) left on the surface of the sample are measured and their arithmetic mean L is calculated. The load considered in the present study is 24.54N and Vickers hardness is calculated using the following equation:

$$H_V = 0.1889\frac{F}{L^2} \quad \text{and} \quad L = \frac{X+Y}{2} \tag{3.1}$$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

3.4 Scanning electron microscopy (SEM)

Scanning electron microscope of Model JEOL JSM-6480LV (Figure 3.2) was used for the morphological characterization of the composite surface. The samples are cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. To enhance the conductivity of the composite samples a thin film of platinum is vacuum evaporated onto them before the micrographs are taken. The fracture morphology of the tensile fracture surface of the composites were also observed by means of SEM.

Figure 3.3 Scanning Electron Microscope Set up

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CHAPTER 4

MECHANICAL CHRACTERISTICS OF COMPOSITES: RESULTS & DISCUSSION

This chapter presents the results of the tests for physical and mechanical properties of short bamboo/glass fiber reinforced epoxy composites. The main aim of this section is comparison between treated and untreated composites and their relevant advantages.

4.1 Mechanical characteristics of hybrid treated fiber epoxy composites

The mechanical properties of the short treated bamboo and glass fiber reinforced epoxy composites with different fiber loading under this investigation are presented in Table 4.1. It is evident from the Table 4.1 that at 15 wt% (bamboo) of alkali treated fiber loading show better mechanical properties as compared to others.

Table 4.1 Mechanical properties of the hybrid fiber epoxy composites

Sample no	Fiber Length (cm)	Fiber loading (bamboo) (%)	Tensile Properties		Flexural Properties		Vicker's Hardness (HV)
			Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	
Set-1 Untreated	1	5	16.15	250.47	51.73	5648.12	9.75
	1	10	16.56	310.22	58.31	6937	11.52
	1	15	16.82	410.14	67.12	5555.11	18.51
Set-2 Alkali treated	1	5	24.25	365.94	84.17	5984	17.7
	1	10	25.45	452.38	67.2	6940.47	15.6
	1	15	27.346	587.58	57.5	8923.50	19.2
Set-3 Permanganate Treated	1	5	15.57	394	46.88	5858	18.85
	1	10	18.04	536.58	72.70	4166	17.6
	1	15	19.63	495.37	82.04	6542.9	19.2

4.2. Effect of chemical treatment on micro hardness of hybrid composites

Figure 4.1 shows the effect of fiber loading on hardness of untreated and treated bamboo/glass fiber reinforced epoxy composites. The results show that with the increase in fiber loading, hardness (HV) value of the treated hybrid composites slightly decreases and then increases with the increase in fiber loading. Inclusion of bamboo fiber in the epoxy matrix body results in improvement in hardness, although this improvement is marginal [43]. However,there is gradual improvement in hardness of the untreated composites as compared with the treated composites (alkali and $KMnO_4$ treatment of the bamboo fibers).

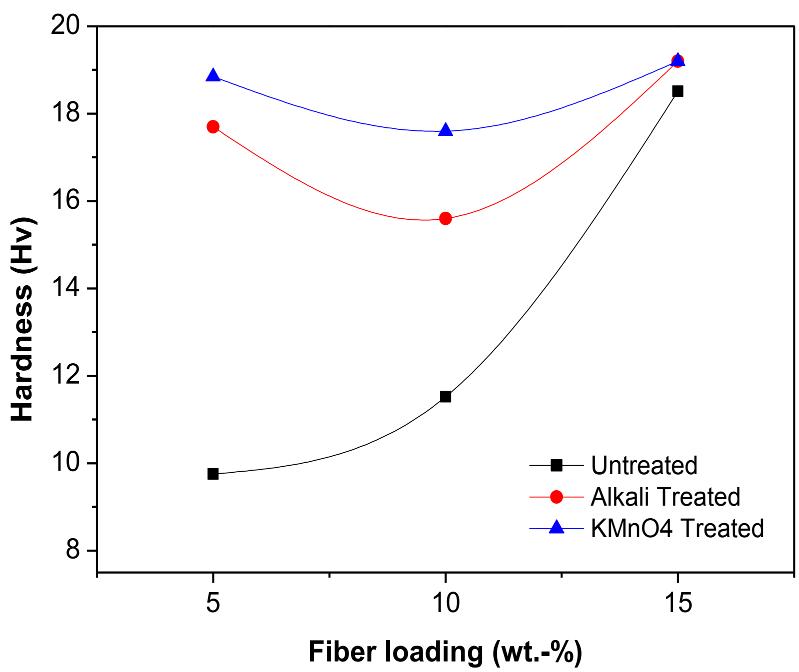

Figure 4.1. Effect of fiber loading on Hardness of hybrid composites

The improvement in the hardness properties could be attributed to the modification of the fiber due to the elimination of hemicellulose from the bamboo fiber body. There may be two reasons to increase the hardness of the treated composites (1) treatment of fibers increased the surface roughness resulting in better mechanical interlocking; and (2) the treatment increased the amount of cellulose exposed on the fiber surface, thus increasing the number of possible reaction sites [44]. Among the three series of composites, $KMnO_4$ treated bamboo/glass epoxy composites show better hardness as compared to the other two series. Saraswathy et al. [45] showed that the increase in hardness is due to increase in polymer concentration and higher molecular weight when working with polyurethanes. Ismail et al. [43] observed that the hardness of natural rubber composite increased with the increasing of filler loading of bamboo fiber from 35 to 65 varying the filler loading (phr) from 0 and 50.

4.3 Effect of chemical treatment on tensile strength and modulus of hybrid composites

The variations in tensile strengths of the composites are shown in Figure 4.2. The tensile strength of the untreated bamboo/glass epoxy composites lies in the range of 16.15MPa to 16.82MPa. Whereas, in case of alkali treatment the strength increases from 24.25MPa to 27.34MPa and for $KMnO_4$ treatment the range has slightly lower values i.e 15.57MPa to 19.63MPa. It is clear from Figure 4.2 that alkali treated bamboo/glass fiber reinforced epoxy composites show better tensile strength as compared with the other two series. Therefore, inclusion of treated bamboo fiber improves the load bearing capacity and the ability to withstand bending of the composites. Similar observations have been reported by Harsha et al. [46] for fiber-reinforced thermoplastics such as poly-aryl-ether-ketone composites. However, for untreated and treated composites the tensile strength increases with the increase in bamboo fiber loading from 5wt.% to 15wt.% respectively irrespective of fiber treatment as shown in Figure 4.2. The tensile strength of alkali treated composites increased by nearly 50% and that of permanganate treated composites decreased by 4% respectively at the ratio of

5:15wt.% bamboo:glass fiber. Whereas, for 10:10 wt. % bamboo glass fiber reinforcement it increased by about 53% and 9% for alkali and permanganate treated composites respectively. Similarly for 15 wt.% bamboo fiber, the tensile strength increased for alkali treated and permanganate treated composites by 63% and 17% respectively. Similarly, as far as tensile modulus is concerned, both the treated and untreated composite modulus increases with the increase in fiber loading as shown in Figure 4.3. It can be observed that in case of 5 wt.% bamboo fiber reinforcement in the hybrid, the modulus increased by nearly 46% and 57% for alkali and permanganate treated composites respectively. For 10 wt.% bamboo fiber reinforcement, tensile modulus increased by 45% and 72% for alkali and permanganate treated composites. Whereas, for 15 wt.% bamboo fiber, it increased by 43% for alkali treated and 21% for permanganate treated composites respectively.

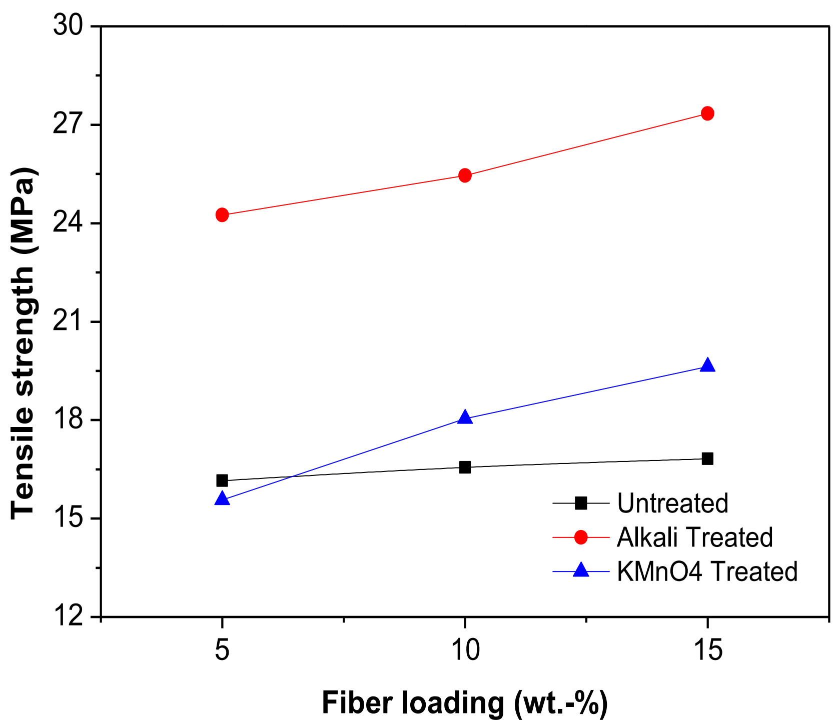

Figure 4.2. Effect of fiber loading on tensile strength of hybrid composites

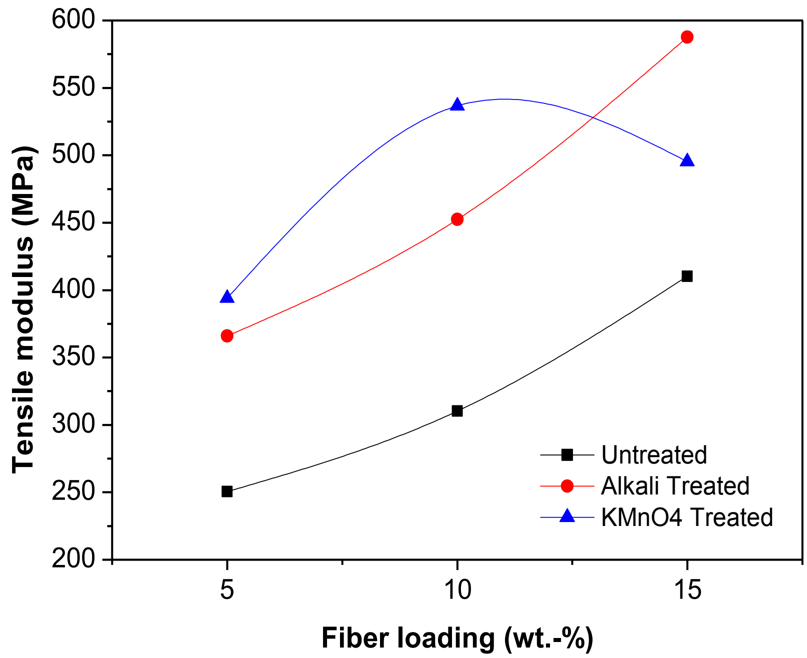

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Figure 4.3. Effect of fiber loading on tensile modulus of hybrid composites

4.4 Effect of chemical treatment on flexural strength and modulus of hybrid composites

The variations in flexural strength of the hybrid composites are shown in Fig. 4.4. Flexural strength of the untreated composites increases with the increase in fiber loading. Flexural strength of treated bamboo epoxy composites is far better than untreated bamboo epoxy composites at lower weight percentages of fiber loading incase of alkali treated. However, in alkali treatment the flexural strength gradually decreases with increase in fiber loading. Whereas, for KMnO4 treatment it shows an increasing trend like untreated fiber reinforcement. The improved flexural properties of the treated bamboo/glass fiber reinforced epoxy composites can be attributed to the physical and chemical changes on the fiber surface effected by the treatments, which actually enhanced the adhesion between the fiber and matrix. This decrease is attributed to the inability of the fiber, irregularly shaped, to support stresses transferred from the polymer matrix and poor interfacial bonding generates partially spaces between fiber and matrix material and as a result generates weak structure [43, 46].

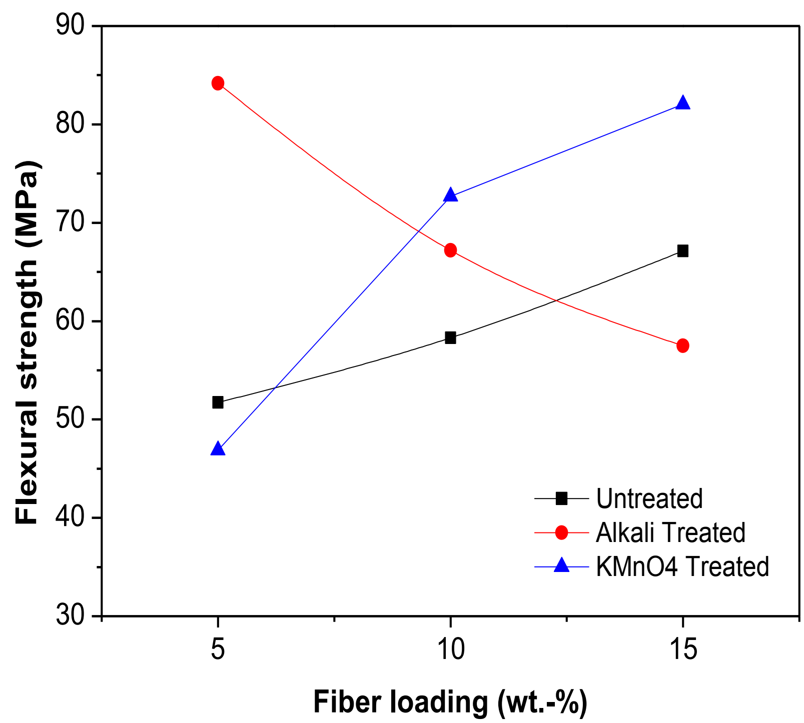


Figure 4.4. Effect of fiber loading on flexural strength of hybrid composites

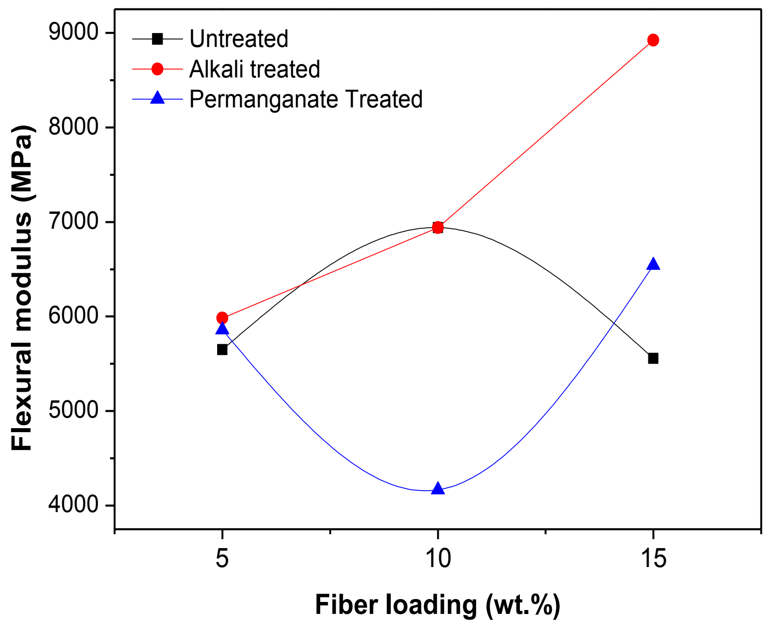
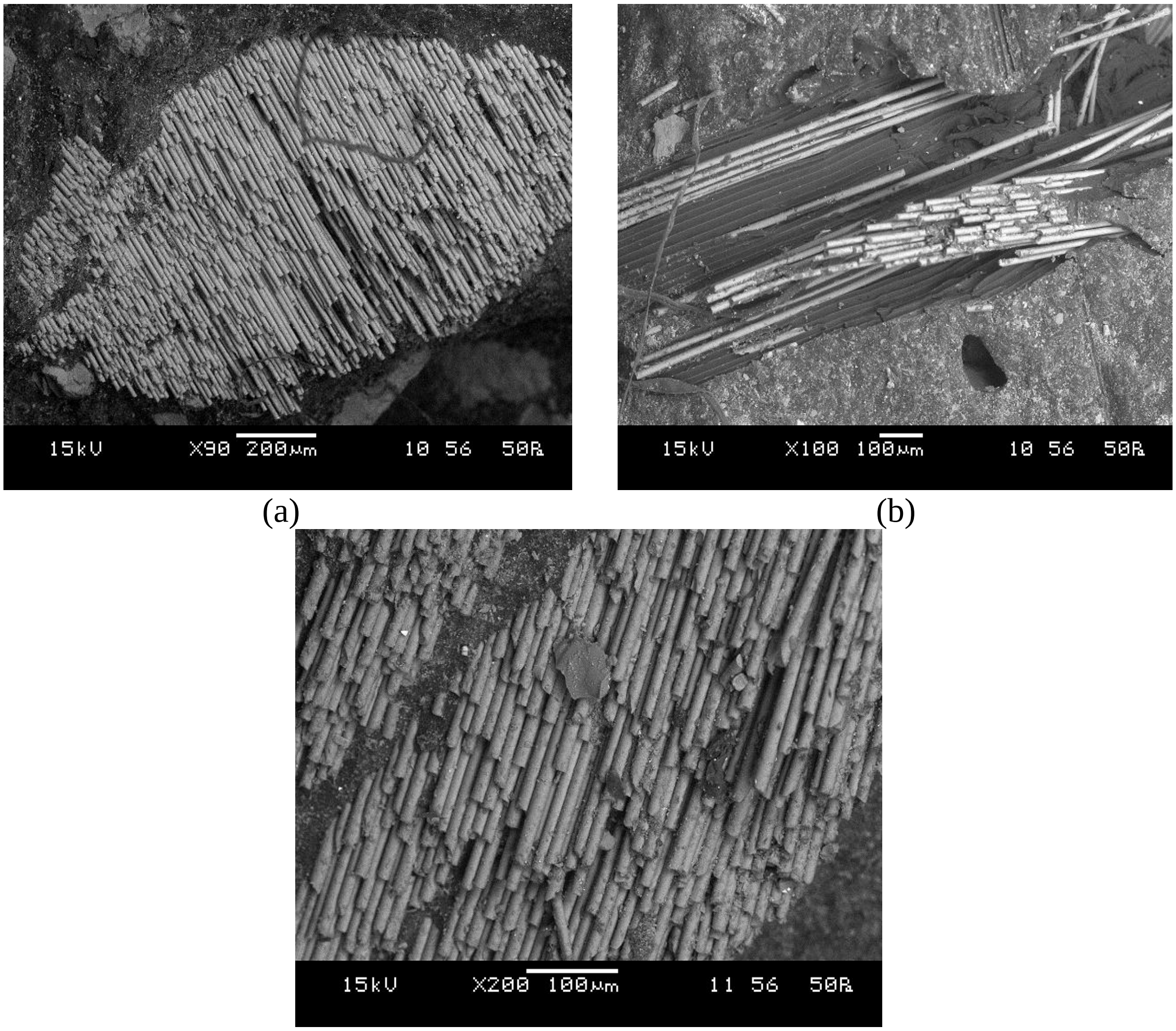


Figure 4.5. Effect of fiber loading on flexural modulus of hybrid composites

Similarly, as far as flexural modulus is concerned for the alkali treated hybrid composites it increases with the increase in fiber loading. Whereas, in KMnO4 treatment the modulus initially decreases up to 10:10wt.% of bamboo: glass fiber ratio reinforcement in the composite and on further increase in bamboo fiber the flexural strength gradually increases. However, in case of untreated composites the flexural modulus shows quite a reverse trend. There can be two reasons for this decline in the strength properties of these composites. One possibility is that the chemical reaction at the interface between the fiber and the matrix may be too weak to transfer the stress; the other is that the corner points of the irregular shaped fibers result in stress concentration in the matrix [47]. The flexural properties are of great importance for any structural element. Composite materials used in structures are prone to fail in bending, and therefore the development of new composites with improved flexural characteristics is essential.

4.5. Surface morphology of the composites

The fracture surfaces study of short bamboo and glass fiber reinforced epoxy composite before and after the tensile test has been shown in Figure 4.6.



(a) (b)

(c)

Figure 4.6. Scanning electron micrographs of glass/bamboo fiber reinforced epoxy composite specimens before and after tensile testing

Figure 4.6(a) shows the fiber reinforced epoxy untreated composite tensile test sample. It is observed from the figure that the fracture surface looks breaking of fiber and matrix body. In case of untreated composites the binding strength between fiber and matrix is lesser stronger then the treated composites. One more possibility is that for untreated composites there may be chances of presence of void in the matrix. However, for alkali treated composite the fracture surface has lesser breaking then the untreated composites as shown in Figure 4.6(b). Similarly, on applying tensile load on KMnO4 treated composites the fractured surface of composite shows breaking of matrix material under initial loading condition (Figure 4.6(c)). The SEM photographs of fractured surface after tensile tests are shown in Fig. 4.6. This is because without fibers to retard the crack growth upon external loading, the crack would propagate in an unstable manner irrespective of fiber loading and treatment. Besides, it is also observed that there is matrix plastic deformation near the fiber-matrix crack zone, which contributes to the plastic zone location in the matrix material. However, with the increase in tensile load up to yield point relatively long extruding fibers can be observed, which is depicted by fiber pullout as shown in Figure 4.6(c). It is an important indication of crack deflection on the matrix surface, where the crack path is changed by the fiber and directed along the fibre surface. This leads to fiber debonding, which is an indication of matrix separation around the fibres as crack intersects the fibre-fiber/matrix interface zone.

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CHAPTER 5
CONCLUSIONS

The present experimental investigation on the effect of chemical treatment on the physical and mechanical behavior of bamboo-glass fiber reinforced hybrid composites leads to the following conclusions

1. The successful fabrications of a new class of epoxy based composites reinforced with short treated and untreated bamboo and glass fibers have been done.
2. The hardness (HV) value of the hybrid composites slightly decreases and then increases with the increase in fiber loading. Inclusion of bamboo fiber in the epoxy matrix body results in improvement in hardness, although this improvement is marginal. However, there is an improvement in hardness of the untreated composites as compared to the treated composites due to Alkali and $KMnO_4$ treatment of the bamboo fibers.
3. The tensile strength of the untreated bamboo/glass epoxy composites lies in the range of 16.15MPa to 16.82MPa. Whereas, for alkali treatment the strength increases from 24.25MPa to 27.34MPa and for $KMnO_4$ treatment the range has slightly lower values i.e 15.57MPa to 19.63MPa.
4. Similarly, as far as tensile modulus is concerned, for 5:15wt.% bamboo: glass fiber reinforcement, the modulus increased nearly by 46% and 50% for alkali and permanganate treated composites respectively. For 10:10 wt.% bamboo: glass fiber reinforcement, tensile modulus increased by 45% and 72% for alkali and permanganate treated composites respectively. Whereas, for 15:5 wt.% bamboo:glass fiber ratio, it increased by 43% for alkali treated and 21% for permanganate treated composites respectively.

5. Flexural strength of the untreated composites increases with the increase in fiber loading. Flexural strength of alkali treated bamboo epoxy composites is far better than untreated bamboo epoxy composites at lower weight percentages of fiber loading. However, in alkali treatment the flexural strength gradually decreases with increase in fiber loading. Whereas, for $KMnO_4$ treatment it shows an increasing trend like untreated fiber reinforcement.
6. The fracture surfaces study of untreated and treated bamboo and glass fibers reinforced epoxy composite after the tensile test has been done. From this analysis it has been observed that for untreated composites the poor interfacial bonding is responsible for low mechanical properties.
7. Possible use of these composites such as roof sealing, pipes carrying coal dust, desert structures, low cost housing etc are recommended. However, this study can be further extended in future to new types of composites using other potential natural fibers/fillers and the resulting experimental findings can be similarly analyzed.

5. 1 Scope for future work

There is a very wide scope for future scholars to explore this area of research in high temperature and erosive environment. This work can be further extended to study other aspects of such composites like use of other potential high strength synthetic fibers for development of hybrid composites and evaluation of their mechanical and wear behavior.

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